An experiment of low cost entertainment robotics

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Abstract— **This paper reports about the robotic installation set up by the Rhoban Project in the French pavilion of the Expo 2012 of Yeosu, Korea ([6]).**

The installation has consisted in a humorous show involving humanoid robots and anthropomorphic arms, with the illusion of life as a guideline. We emphasized natural compliant motion and physical interaction in order to make the show attractive.

The design rised some issues dealing with robustness of robots, but also realism of the motions and the synchronization of the robots with the music.

Keywords. Robots in Art and Entertainment, Human/Robot Interaction, Humanoid Robotics.

Fig. 1. The show

INTRODUCTION

Little by little, entertainment becomes an important application of robotics. Some main stream robots like e.g. HRP-4C ([10]) target entertainment as an important application. We can find a lot of robots in amusement parks like Disneyland which counts several robots in all its attractions. Korea is currently completing a whole park focused on robots ([4]), this demonstrates that robots attracts people. This paper reports about the robotic installation in the French pavilion of the Expo 2012 of Yeosu, Korea, set up by the Rhoban Project [1].

The show consisted of humanoid robots and real size robotic anthropomorphic arms, our goal was to illustrate the use of *compliance* in low cost robotic within a funny installation. The arms were staged as a farcical fake rock band made of arms without body (which do not really play), while a humanoid robot was dancing and interacting with people and two other ones were on a swing under a tree.

We set up the installation with *illusion of life* as a guideline. First, we made possible the physical interaction between people. Concretely, people could take the hands of humanoid robots and interact physically with them. Comparing to a simple computer, the essence of the robot is the sensorimotor system, and the possibility to feel this system directly by touching turned out to be very attractive. Moreover, it provided an illusion of life to people, beyond the look and the appearence of robots.

Second, we wanted to illustrate compliant motions, still to provide lifelike behavior. To do that, we set up a swing installation where a robot was seated on a swing under a tree and an other robot pushed him regularly. This showed a compliant natural physical interaction between robots.

Third, we set up a farcical sketch as a robotic rock band made only of arms. The goal was at first humorous, showing kind of awkward arms playing and dancing in front of people. Again, an illusion of life appeared from rythmic synchronisation, but also from a kind of clumsiness.

Along this design, we had to face several difficulties.

At first, the cost constraints were important. Particularly, we designed the arms with less that $2000 each, which is not comparable to a small industrial arm of comparable size. This drove us to use small scaled motors, implying precision and torque problems. However, in the entertainment framework, this constraint is strong and omnipresent. Indeed, if we think about issuing at large scale personal robots dedicated to entertainment, costs are a crucial issue. Thinking about toys as an extremal example.

A second difficulty, related to the first one, was to keep a high level of robustness and reliability, for security reasons, but also for production reasons. Indeed, the show had to work 12h/day, 7 days/ 7 during 3 months. People interacted with robot all the time. This point implied a heavy work at all levels (mechanics, electric, electronic and software).

One of the most popular robot band is certainly Compressorhead (see [2]), those hobbyist's robots use hydraulic system to actually play music that human can't technically play. They used bass, guitar and drums. Even if the robots structure is build to look familiar, they aren't humanoid because their structure was adapted to play music. Another famous music playing robots are the Toyota Parner Robots [3] they were first introduced at the 2005 World Expo in Japan. The world most famous humanoid robot, Honda's Asimo [7], [8] also conducted the Detroit Symphony Orchestra during a demonstration [1]. As explained in [9], research

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1. Rhoban Project is a group mixing academic researchers, artists and others people interested in designing original robotic creatures, see www.rhoban-project.org

in musical robotics focuses essentially on the production of sound, and often doesn't take account of robot's aspect. Actually, the main stream goal of work in this domain is to make robots coplaying with humans in live performances.

Our work was different because our robots weren't actually playing their instruments, but faking it with illusion of life. This is the reason why we only considered the apparence of the show and especially the motions, trying to make it look pleasant and entertaining. In fine, about 600 000 people visited the installation.

The authors want to thank *P.-Y. Oudeyer* and the *Flowers team* for many precious ideas and also for some technical support.

Video of the show :
`http://www.youtube.com/watch?v=F9W4NyD5XsI`
The hand of the anthropomorphic arm :
`http://www.youtube.com/watch?v=g7vo01mBixc`
See also :
`http://www.rhoban-project.org/RobotsYeosu.html`

I. Robots

A. Humanoids

The show included two distinct small lightweight humanoid robots : a new version of Acroban robot substituting ([11], [13]) and the SigmaBan robot.

Acroban has been designed in collaboration with the Flowers Inria team, one of the goals was to study compliance and semi-passive dynamics. SigmanBan has been designed to study biped locomotion. It is smaller than Acroban which allows him particularly to get up. We use him mainly to participate to the RoboCup[5] championship in kidsize league.

The mechanical structure of SigmaBan involves 22 degrees of freedom : 6 for each leg, 2 for the pelvis (rotation in the sagittal plane and in the coronal plane), 3 for each arm, and 2 for the head (pitch and yaw rotations). The shape of the robot is globally standard.

On top of that, Acroban has a multi-articulated spine including 5 joints. This feature makes grow the operational space, it also enriches motions, especially for locomotion and interaction.

Our design focuses on *the compliance of the structure*. Our goal is to improve the intrinsic stability of the system, and to avoid as much as possible inelastic shocks. Accordingly, we included several springs to the structure, as well as some flexible and soft materials like plastics and foam.

In this new version of Acroban and in SigmaBan, we introduced free linear joints controlled by *dampers* only in the hips. These joints absorb vertical shocks occuring during the gait, especially at the landing of the foot on the ground. They are located in the hips, allowing a vertical linear motion. These joints introduce new not-controlled degrees of freedom, making the robot *semi-passive*. Moreover, the dampers are also used in another way, that is, as feedback

Fig. 2. Integration of Dampers in the Hip

force sensors. The vertical dampers located in the hips directly samples the ground reaction force. This force can thus be computed from the measure of the length of the damper by taking account of its friction and spring coefficients, what we do by using linear potentiometers. Even if more complex control is involved, the empirical experiments have showed very good stability properties, and new possibilities for improving the robot motions.

B. Anthropomorphic Arms

The arms have been designed especially for the show. The challenge has been to reconcile contraints due to low cost and their implications in the available torque and the real size (their length is about 60cm).

Fig. 3. The arms

We use the same kind of motors than Acroban and SigmaBan, i.e., Dynamixel RX-28 / RX-64 / RX-106. In order to conterbalance the lack of torque in the motor, the joints are supported by springs and elastics, in the shoulder and in the elbow, to have a more comfortable stable position.

The arm in itself is provided with 7 joints : 2 in the shoulder, 2 in the elbow and 3 in wrist. This gives an anthropomorphic design allowing natural motions.

The hand comes in addition : it includes 4 to 12 joints (we have designed several versions). In the more sophisticated version, it includes 2 joints in each fingers plus 2 additionnal joints for the global lateral aperture of the hand. The design of the hand relies on prototyping technics inspired from those developped in the ECCE Robot project ([12]). A detailled video of the 12 degrees-of-freedom hand is available here :
`http://www.youtube.com/watch?v=g7vo01mBixc`

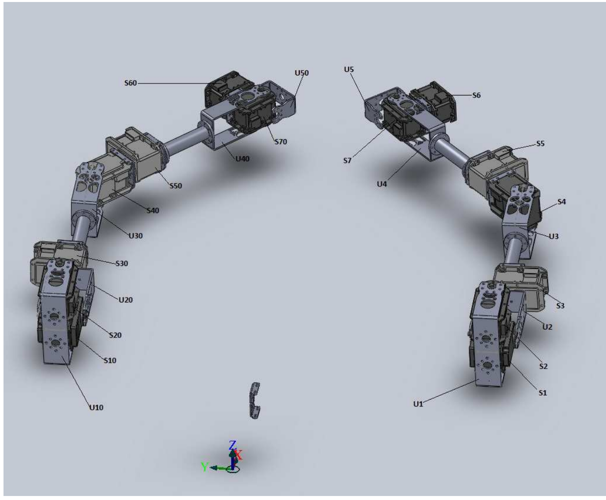


Fig. 4. Anthropomorphic Arm Design

The main problem in the design of the hand has been the integration of the joints. We used micro-servomotors actuating joints via a hand made cables network.

Our main goal in the design of the hand, and actually of the arm, has been to allow natural and lifelike motions. However, its mobility richness should allow interesting prehension experiments in the future.

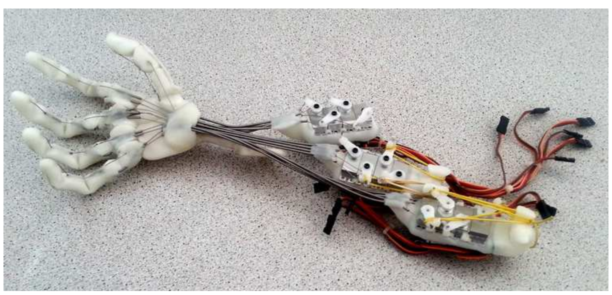


Fig. 5. The 12-degrees of freedom hand

II. Robotic Installation in the French Pavilion of Yeosu Expo 2012

Our robots have been chosen to animate the third room of the Expo'2012 french pavilion, this room is called "the cellular garden", as a symbol of harmony between nature and high technology.

A video of the show is available at :
`http://www.youtube.com/watch?v=F9W4NyD5XsI`

A. *Humanoid robots*

A small humanoid robot of the SigmaBan series is doing tree swing while a taller robot from the Acroban series is pushing him periodically to keep Sigmaban moving back and forth. This installation shows how our robots can interact physically thanks to compliant control. Indeed, the arms and the spine of Acroban are compliant. This allows Acroban to absorb the shock, and also to detect it. Let us note that compliance is enforced mechanically (thanks to dampers in particular) but also in the control (see [11]). From this, the motor primitive produced a push action to throw the swing with the pelvis, the spine and the arms.

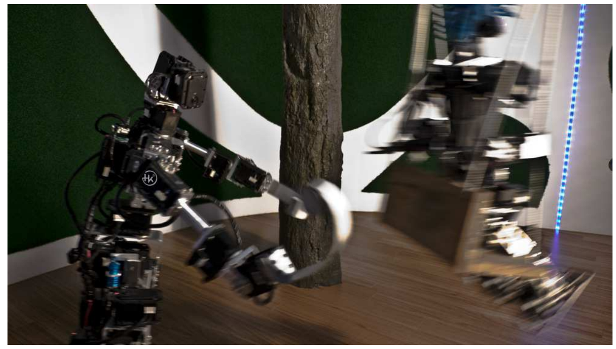


Fig. 6. The swing installation

In parallel, Acroban runs an independant motor primitive aiming at keeping balance. This is essential to prevent him from fall.

The other Acroban robot performs dances synchronously with arms, and sometime interacts with people. In this case, his arms and his spine are made compliant, and people can take his hands and play with him. The interaction motion is an ad-hoc designed motor primitive. It makes the torso and the head follow sollicitations of people. But at the same time, the robot, while interacting, keeps its balance with the pelvis and the legs. The mix of the two motions turned out to produce a very natural and attractive behaviour.

B. *Rhoban Sound System*

On the other side of the room, a rock'n'roll show is performed periodically by five pairs of real size anthropomorphic arms. The robots don't really play. They are stagged to animate people, seeming playing sometimes, dancing at some other times.

First, the staging has been an important concern. We took the option of giving a humoristic parody performance. The robots start the show as if they really played music, and quickly, they let instruments and perfom some dances and synchronous funny motions, making people laugh.

Second, at the level of motion themselves, material constraints did not allow high precision ; however, the richness of degree of freedom in our design, together with compliance control allowed to design smooth, natural motions. On top of that, we used several methods to design motions ; among them, we used demonstration learning methods, where the motion is first executed by the operator, and then processed and replayed by the robot. This enforced significantly the natural aspect.

Technically, the synchronisation of robots is very important for the good understanding for people. The orchestration is designed automatically from midi files (see Section III-E).

Finally, even if motions are not perfect in term of precision, they gave an real illusion of life to people.

The show of the band (called *Rhoban Sound System*) occured every 10mn, during 3mn.

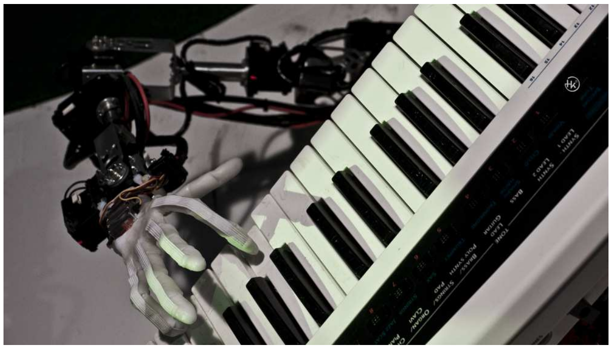
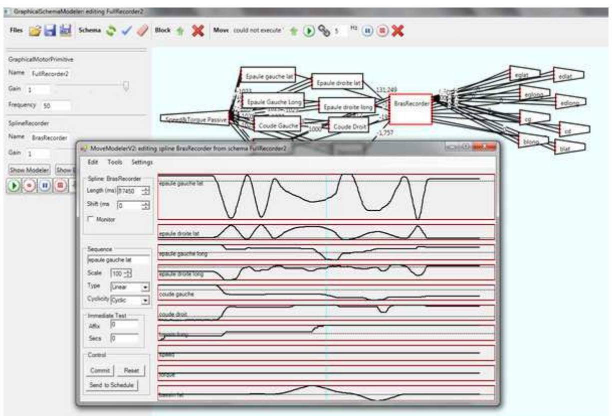


Fig. 7. One of the ten robotic arms

III. Motions

A. Motion Control

We designed motions through a graphical framework environment that we have developed where motions are subdivided into modules called parameterized motor primitives. Here is the general aspect of this environment :



Motor primitives are combined in order to form global motions of the robot in a modular way. At each time, each active motor primitive computes relative output values ; then, for each output, all these computed values are weighted and added to get the final output value. In turn, motor primitives are themselves organized in a classical way as block schemes involving inputs, basic blocks (filters) and outputs defined as follows :

Inputs of the motor control system taken into consideration :

- *Sensors.* The humanoid robots is equipped with a 3-axis accelerometer and a 2-axis gyro located on the hip. One also uses the length of the linear joints in the hips.
- *Internal Motor Position.* position error. When the motor is compliant, it makes an error in position regarding its position target. This position error can be measured accurately and is extensively used in the motor primitives. Motors can also return the load, i.e., the torque applied to the motor.
- *External Interfaces.* Essentially during test phases, we used a joypad to control the parameters of certain motor primitive in real-time.
- *Splines.* Inputs can also be splines, which are in our case piecewise linear functions defined by the user point by point. Let us note that seeing that the frequency of the motor control system is low, piecewise linear functions give already satisfying results.
- *Periodic functions.* One can also use periodic functions (typically trigonometric functions) as input. This is used essentially to define Central Pattern Generator (CPG for short) as motor primitives.

Outputs of the motor control system took into consideration :

- *Joint positions.* This is the most basic output of the motor primitive system. It consists in fixing the target position of a particular joint.
- *Joint maximal torque.* It fixes a bound for the torque enforced by a particular servomotor. This parameter is crucial to control the compliance of motion.
- *Operational space position.* Partial inverse kinematic is computed onboard by the platform : Cartesian position of each foot. It means that one can give orders concerning the Cartesian position of each foot. For the humanoid robot, one uses inverse kinematic for the feet. For arms, one uses it for hands.
- *Motor Primitive Parameters.* Some motor primitive parameters can be also used as output of the system. It means that a basic block can be used to modify for instance the amplitude of a particular spline. In a similar way, gains of outputs, of filters, speed of CPG can also be modified in this way.

The following classical types of blocks are available : proportional controller, weighted sum, mobile average, phase shift, discrete variation and integrator, PID, variation bound. In addition, one can define maximum and minimal bounds for each block input and output. Blocks can be combined with each other. For instance, this can be used to enforce PID controllers.

B. Motion Design

In this installation, our method for motion design has been mostly empirical. We used the motion design environment to define motor primitives, exploiting sensors traces and adjusting parameters by experiments. The dancing motions are generated by mean of periodic functions, imitating CPG, and splines. For humanoid, the motor primitive are runed in parallel to the balance keeping motor primitive.

In the same way, elementary motions of the arms are produced by a mix of periodic motion and splines. In this case, the design of motions mostly relies on demonstrations by direct manipulation of the robot, which records and synthetises motions. Then, these elementary motions are combined according to the music (see below). Let us note that accordingly to the strong constraints on the torque, we have to take care every time at the power consumption, when we're designing the movement.

Concerning the balance keeping in particular, in the sagittal plane, independant motions actuating knees, hip and feet are enforced by PID controllers whose gain are adjusted by expert knowledge and experiments. We also used compliance in the sagittal rotation of the lower joint of the vertebral column, enforced in a spring mode. Error is re-injected in the sagittal rotation of the shoulder and in the pelvis sagittal horizontal position via a PID controller.

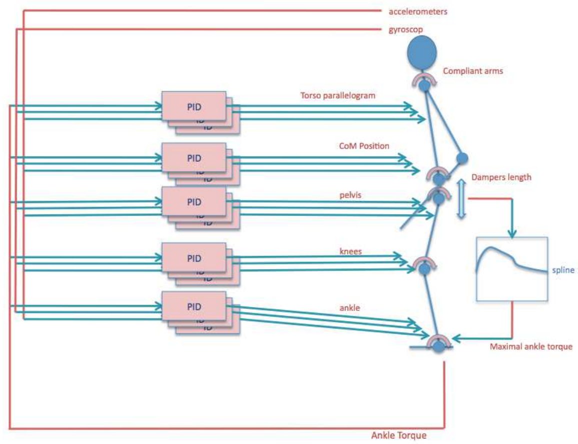


Fig. 8. Balance Keeping

C. Global Architecture

The installation is supervised by an autonomous control and monitoring system running on a PC and connected by ethernet to the three humanoids and the five pairs of arms. A C#-based control system synchronizes all events in the room : running and stopping the moves of the humanoid robots and of the robotic arms, playing the music of the show, delivering media on screens (see below).

Each humanoid is equipped with kinetic sensors and an ARM9 control card. Each of the five pairs of arms is equipped with two boards, the ARM9-based card running Linux is used to control moves of the joints and to communicate with the control PC while the ARM7-based card is driving the fingers moves.

D. Monitoring and maintenance

The system also continuously monitors temperatures and positions of dynamixel servos. This is an essential part of the architecture that helps to detect and to prevent hardware failures.

The main problem we met was the wires failures. All the motors were on a serial half-duplex bus, which allowed us to give the orders and torque limit, but also to read their positions, torque, and status like the temperature or input voltage. The bus speed was about 1 megabaud (i.e, 1 million of bits per seconds), and packets that we sent to the motor had a timeout less than 1ms. Reading errors occur frequently on this kind of bus, because the all mechanical structure of the robots is always moving and the motors needed to deal with the position control and the communication at the same time. Especially, we noticied that reading errors growed up significantly because a wire definitely failed (because of a weak soldering for instance).

That's the reason why we set up a system to monitor these reading errors on the bus globally, i.e, all the robots and all the buses on the same screen. With this tool, we were able to prevent most of the failures and replace the wires before actual troubles.

E. Synchronization with the music

The sound of the show was a music piece produced by a french team and recorded with real instruments. They also provided us the perfect matching MIDI file, which is basically like a sheet music.

All the robots were available on a network, and we drove them from a supervisor computer though TCP connections. We designed a software to allow scripts editions and work on the global scenography. Each robots having its own elementary motion, we could then organize them with a timeline :

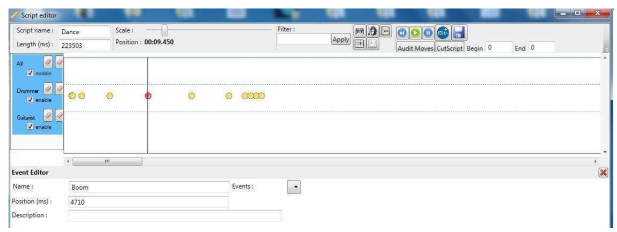


Fig. 9. Control Time Line

We generated a first script automatically by importing the MIDI notes, and mapping the MIDI instruments with the robots of the show. We then mapped those notes with more complex events themself able to involve several actions like starting, pausing, stopping moves or updating parameters on currently running moves. Each of these actions was executed with an offset relative to the events they were attached, so that move could anticipate the music. For instance, the move that makes the robot hit a drum was run before the note so the moment when the stick hit the drum accurately matches the moment when the sound of the note was.

We then manually changed the show, and reworked it parts after parts with the timeline editor.

IV. Conclusion

We have designed and maintained a complete robotic show, including several humanoid robots.

We tried to make the show attractive by trying to enforce a kind of illusion of life with robotics. First, at the staging level, the swing or the robotic band made robots adopt human being posture. Second, at the motion level, the compliance together with the richness of joints allowed us to design natural motions. Third, the compliance allowed us to enforce physical interaction, which turned out to be very attractive and original for people.

At the engineering level, the robustness and the reliability has been a constant concern for us. Let us note that the pressure is high in the entertainment framework ; this makes difficult to enforce classical project development cycle and then ensure reasonable level of reliability.

However, the show worked during 3 month without interruption, and about 600 000 people came and saw the robots.

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